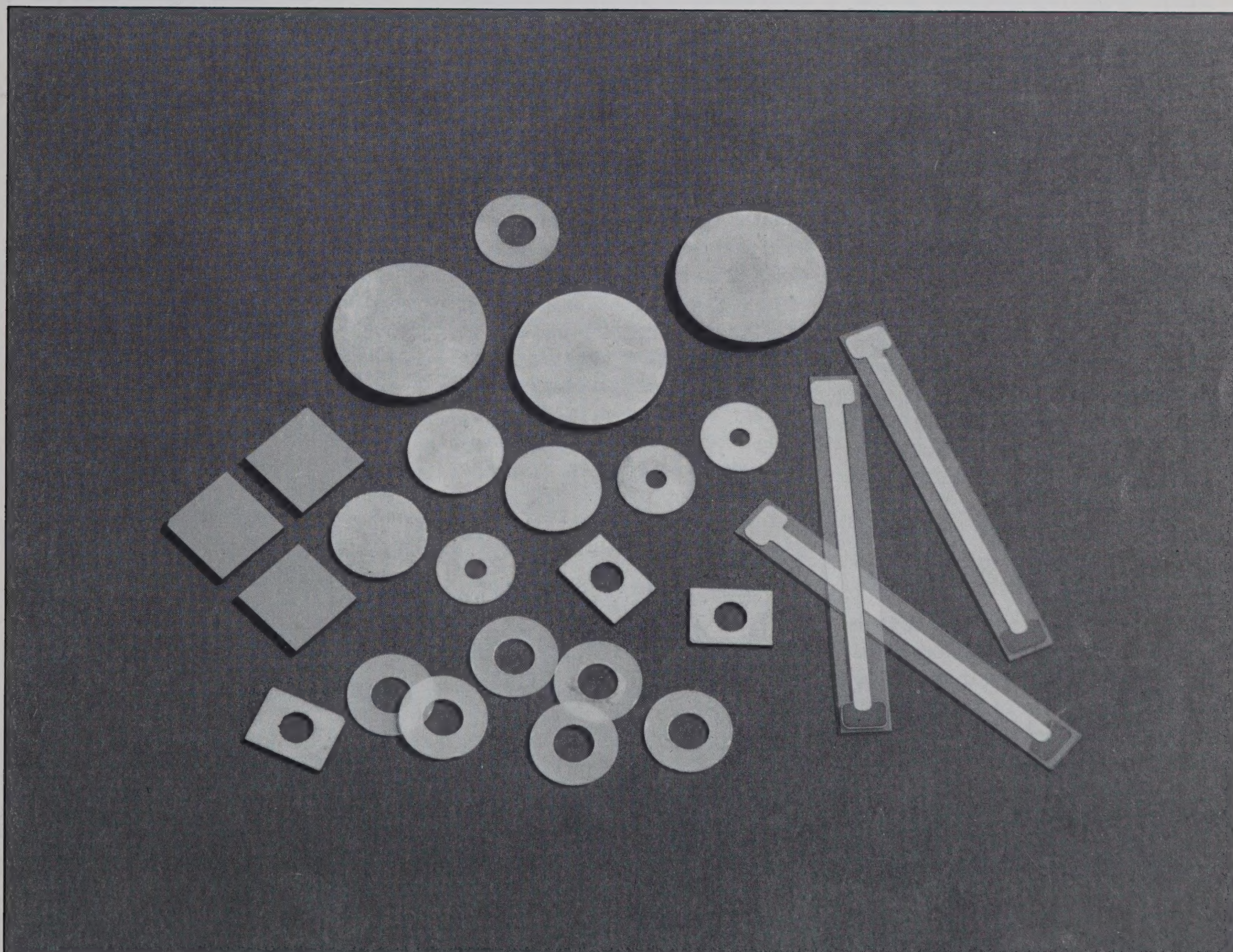
LITHIUM NIOBATE AND LITHIUM TANTALATE

ACOUSTICAL CRYSTALS

VERY HIGH PIEZOELECTRIC COUPLING
LOW DIELECTRIC CONSTANT
BROAD BANDWIDTH CAPABILITY
CONSISTENT ACOUSTIC PROPERTIES
LOW ACOUSTIC LOSS



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INTRODUCTION

Both lithium niobate and lithium tantalate are ferroelectric crystals which possess high Curie temperatures. These crystals exhibit excellent piezoelectric coupling coefficients, making them attractive for ultrasonic device applications. Both crystals are grown by the Czochralski technique which yields large, high quality single crystals in a number of different growth directions. The crystals are poled into single domain by applying a field of a few volts/cm to the crystal at the Curie temperature and then cooling slowly to permanently freeze the domains in place. The result is a uniform, highly consistent piezoelectric transducer single crystal.

Lithium niobate possesses a number of useful cuts which are now extensively used in transducer applications. Two compressional cuts are popular, the z-cut and the 36° rotated y-cut. The shear mode cuts most commonly used are the x-cut and the 163° rotated y-cut. Detailed properties for these cuts are described in the accompanying data.

Lithium tantalate also possesses useful cuts for compressional and shear wave mode transducers. The two most popular compressional cuts are the z-cut and the 47° rotated y-cut, while the x-cut and the 165° rotated y-cut are the most commonly used shear mode cuts. Properties for these cuts are also detailed in the accompanying data.

APPLICATIONS

Lithium niobate possesses very large piezoelectric coupling coefficients — several times larger than quartz — and very low acoustic losses. Because of its Curie temperature of 1150°C, it can be utilized as a high temperature acoustic transducer. It may also be employed as a transmitter and/or a receiver of acoustic vibrations.

Due to its useful acoustic properties and high temperature capability, lithium niobate has been employed as a safety device to warn of the onset of boiling in a liquid-metal-cooled fast breeder reactor by detecting the associated acoustic vibrations. In addition, it has been used in high temperature accelerometer applications for the same reasons, which has most recently included use as an accelerometer for jet aircraft. Acoustic wave delay lines and acousto-optic modulators, deflectors, and filters now routinely employ lithium niobate for both shear and compressional wave generators because of its high efficiency, broad bandwidth capability, low dielectric constant for all orientations, and consistent repeatability.

Like lithium niobate, the major advantage lithium tantalate has over quartz is its much larger piezoelectric coupling. Although the piezoelectric coupling coefficient of lithium tantalate is not as large as that of lithium niobate, lithium tantalate does possess a number of zero temperature coefficient cuts of resonant frequency for all the major modes of vibration. As a result, it finds application in communications as an acoustic resonator filter. This enables broader bandwidth filters to be designed which do not employ lossy inductors to achieve the desired bandwidth requirements.

Several lithium tantalate length extensional resonator filters have been designed by AT&T Bell Laboratories which operate in the kilohertz and low megahertz region of the frequency spectrum. Spurious mode generation in lithium tantalate devices is generally less than in comparable devices. Future monolithic filter designs on lithium tantalate are expected to provide higher frequency resonators, up to 180 MHz in the third harmonic, with substantially larger bandwidths than are available in quartz devices now.

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PHYSICAL PROPERTIES

	$LiNbO_3$	$LiTaO_3$
Crystal Class	Rhombohedral [1,2]	Rhombohedral [3,4]
Space Group	R3c or C_{3v}^{6} [1,2]	R3c or C_{3v}^{6} [3,4]
Point Group	3m or C_{3v} [5]	3m or C_{3v} [3,4]
Lattice Constants Rhombohedral	a_{Rh} = 5.4944Å [1] α_{Rh} = 55° 52′	a_{Rh} = 5.4740Å [6] α_{Rh} = 56° 10.5′
Equivalent Hexagonal	a_H = 5.1483Å [1] c_H = 13.8631Å	a_H = 5.15428Å [6] c_H = 13.78351Å
Density	4.64 g/cm^3 [7]	7.45 g/cm^3 [8]
Molecular Weight	147.85	235.88
Melting Point	1253° C [9]	1650° C [10]
Curie Point	1150° C	610° C [11]
Moh Hardness	5 [7]	5.5 - 6.0

	$LiNbO_3$	$LiTaO_3$
Solubility	Insoluble in water; practically inert to room temperature acids	Insoluble in water; practically inert to room temperature acids
Thermal Expansion Coefficient (0-110°C)	$\alpha_a = 15.4 \times 10^{-6}/°C$ [12] $\alpha_c = 7.5 \times 10^{-6}/°C$	$\alpha_a = 16.1 \times 10^{-6}/°C$ [12] $\alpha_c = 4.1 \times 10^{-6}/°C$
Thermal Conductivity	1×10^{-2} cal/cm-sec-°C	—
Pyroelectric Coefficient @ 27°C, μcoulomb/cm^2/°C	0.0083 [14]	0.019 [15]
Birefringence (n_e-n_o)	≈ -0.08	≈ +0.004
Hydrostatic Piezoelectric [16] Constants @ 21°C	6.31×10^{-12} coulomb/newton	2.00×10^{-12} coulomb/newton

PIEZOELECTRIC CONSTANTS @ 25°C

Constant Stress			Constant Strain		
	$LiNbO_3$	$LiTaO_3$		$LiNbO_3$	$LiTaO_3$
e_{15} [12,17]	3.83 coulomb/m^2	2.72 coulomb/m^2	d_{15} [12]	6.92×10^{-11} coulomb/newton	2.64×10^{-11} coulomb/newton
e_{22}	2.37	1.67	d_{22}	2.08	0.75
e_{31}	0.23	-0.38	d_{31}	-0.085	-0.30
e_{33}	1.80	1.09	d_{33}	0.60	0.57
g_{15} [18]	9.1×10^{-2} m^2/coulomb	5.8×10^{-2} m^2/coulomb	h_{15} [18]	9.5×10^{9} newton/coulomb	7.2×10^{9} newton/coulomb
g_{22}	2.8	1.5	h_{22}	6.4	4.3
g_{31}	-0.4	-0.6	h_{31}	0.8	0.0
g_{33}	2.3	2.1	h_{33}	5.1	5.0

SELECTIVE PIEZOELECTRIC COUPLING FACTORS & FREQUENCY CONSTANTS [18]

		$LiNbO_3$		$LiTaO_3$	
Plate Orientation	Wave Type	Coupling Factor	Resonant Frequency Constant (MHz-mm)	Coupling Factor	Resonant Frequency Constant (MHz-mm)
X	S	0.68	1.838	0.44	1.906
Z	C	0.17	3.615	0.19	3.040
36° rotated y-cut	QC	0.49	3.300	—	—
47° rotated y-cut	QC	—	—	0.29	3.080
163° rotated y-cut	QS	0.62	1.866	—	—
165° rotated y-cut	QS	—	—	0.41	1.830

C = compressional, S = shear, QC = quasi-compressional, QS = quasi-shear

ELASTIC WAVE VELOCITIES [12]

Propagation Direction	Polarization Direction	Wave Type	Velocity (× 10^3m/sec) $LiNbO_3$	$LiTaO_3$
X	X	C	—	5.5522
X	Y	S	4.0593	3.3556
X	Z	S	4.8012	4.2202
Y	Y	QC	6.8822	5.6917
Y	X	S	3.9615	3.5297
Y	Z	QS	4.4943	—
Z	Z	C	7.3328	6.1607
Z	X, Y	S	3.5740	3.6039

ELASTIC STIFFNESS CONSTANTS
× 10^{11} newton/m^2 @ 25°C

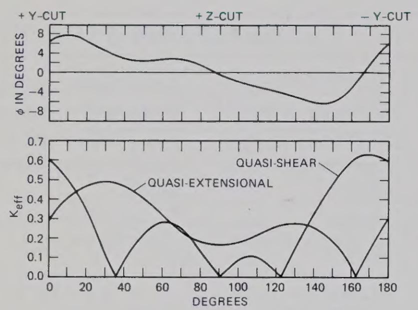
	$LiNbO_3$		$LiTaO_3$	
	Constant [12] Field (E)	Constant [18] Displacement (D)	Constant [12] Field (E)	Constant [18] Displacement (D)
c_{11}	2.030	2.19	2.298	2.39
c_{12}	0.573	0.37	0.440	0.41
c_{13}	0.752	0.76	0.812	0.80
c_{14}	0.085	-0.15	-0.104	-0.22
c_{33}	2.424	2.52	2.798	2.84
c_{44}	0.595	0.95	0.968	1.13
c_{66}	0.728	0.91	0.929	0.99

ELASTIC COMPLIANCE CONSTANTS
× 10^{-12} newton/m^2 @ 25°C

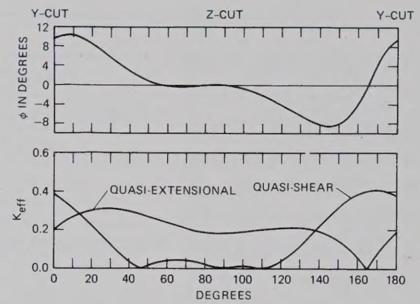
	$LiNbO_3$		$LiTaO_3$	
	Constant [12] Field (E)	Constant [18] Displacement (D)	Constant [12] Field (E)	Constant [18] Displacement (D)
s_{11}	5.831	5.20	4.930	4.76
s_{12}	-1.150	-0.44	-0.519	-0.50
s_{13}	-1.452	-1.45	-1.280	-1.20
s_{14}	-1.000	0.87	0.588	1.02
s_{33}	5.026	4.89	4.317	4.19
s_{44}	17.10	10.8	10.46	9.3
s_{66}	13.96	11.3	10.96	10.5

DIELECTRIC PROPERTIES

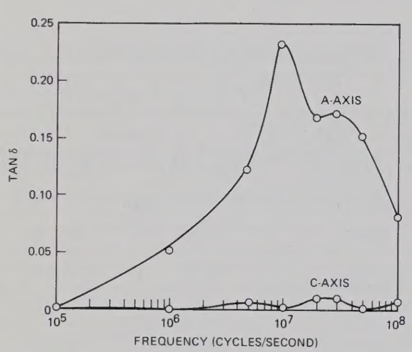
		$LiNbO_3$	$LiTaO_3$
Electrical Resistivity ohm-cm		5×10^8 (400°C) [7] 140 (1200°C)	$\approx 10^{13}$ [19]
Dielectric [12] Permittivity Constants $\times 10^{-9}$ farad/m	ϵ_{11}^{S}	0.392	0.377
	ϵ_{33}^{S}	0.247	0.379
	ϵ_{11}^{T}	0.754	0.474
	ϵ_{33}^{T}	0.254	0.384



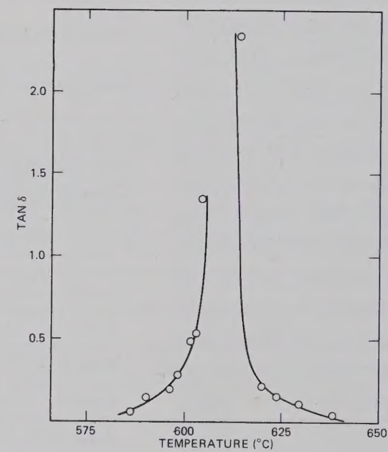
Effective coupling factors and angle ϕ between quasi-compressional wave displacement and plate normal for rotated y-cuts of $LiNbO_3$.[18]



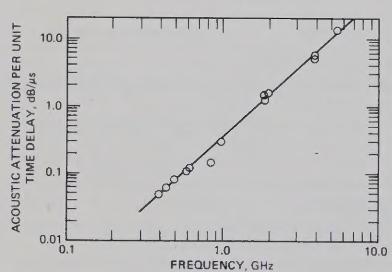
Effective coupling factors and angle ϕ between quasi-compressional wave displacement and plate normal for rotated y-cuts of $LiTaO_3$.[18]



Loss tangent variation of $LiNbO_3$ with frequency at 25° C.[7]



Loss tangent of $LiTaO_3$ as a function of temperature near the Curie point.[20]



Acoustic compressional wave attenuation in $LiNbO_3$ at room temperature.[21]

LOSS TANGENT OF $LiNbO_3$ AT 10^5 Hz [7]

T(°C)	tan δ c-axis	tan δ a-axis
400	0.001	0.0006
500	0.016	0.01
600	0.12	0.1
700	1.0	0.8
800	5	8
900	11	25

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